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USING COST ANALYSIS TO BREAK THE OVERRUN HABIT.(U)

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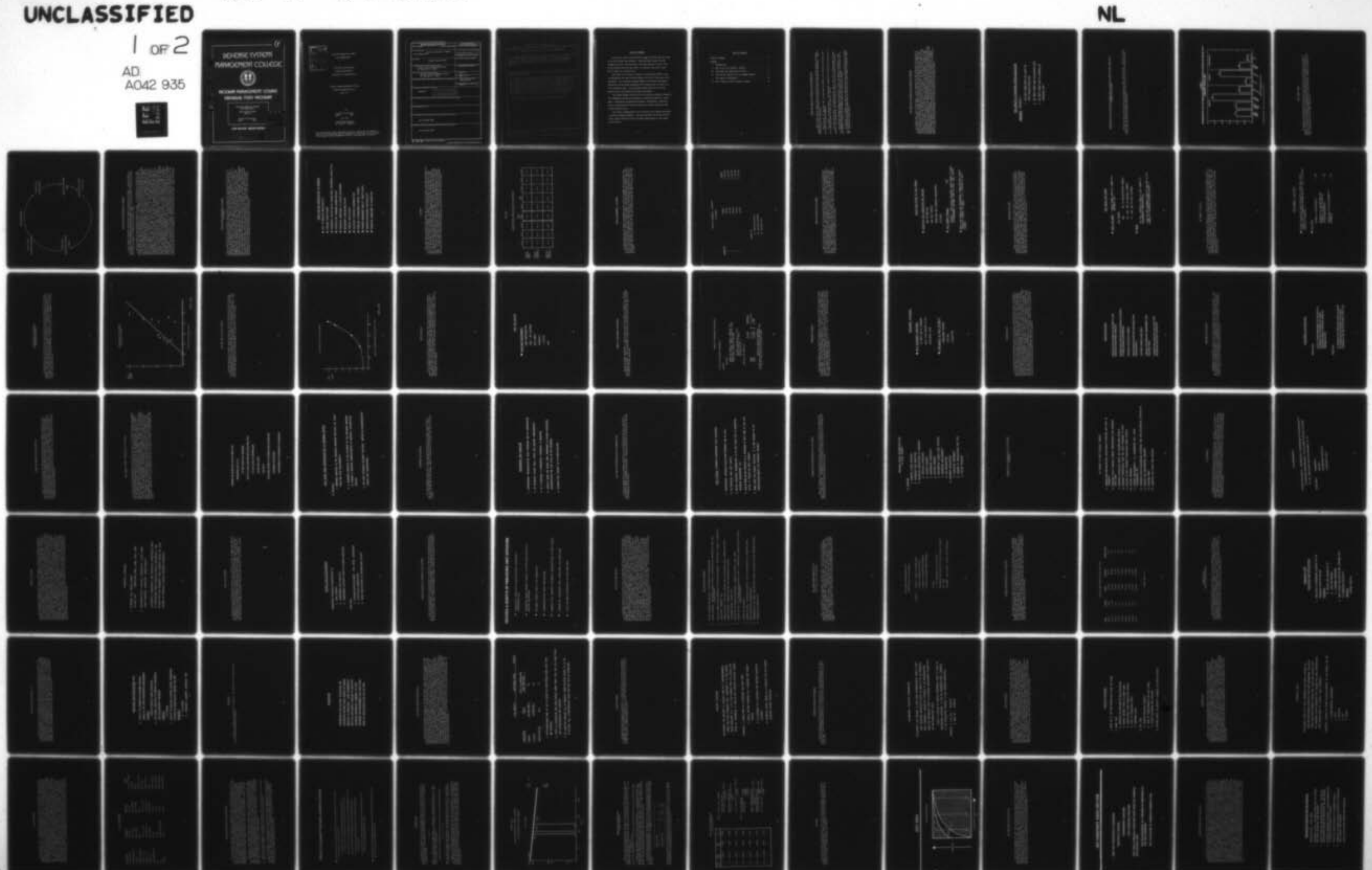

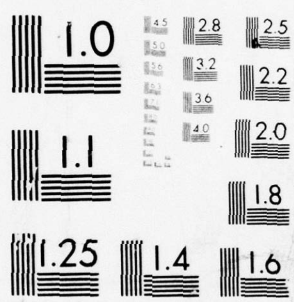

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DEFENSE SYSTEMS MANAGEMENT COLLEGE

DEPARTMENT OF DEFENSE SYSTEMS MANAGEMENT COLLEGE
DUCTUS DOCTRINA DOMINATO

PROGRAM MANAGEMENT COURSE
INDIVIDUAL STUDY PROGRAM

USING COST ANALYSIS TO BREAK
THE OVERRUN HABIT

STUDY PROJECT REPORT
PMC 77-1

Richard William Grimm
Major USAF

FORT BELVOIR, VIRGINIA 22060

USING COST ANALYSIS TO BREAK THE OVERRUN HABIT

Individual Study Program

Study Project Report

Prepared as a Teaching Paper

Defense Systems Management College

Program Management Course

Class 77-1

by

Richard William Grimm
Major USAF

May 1977

Study Project Advisor
Mr. Arnold G. McManamon

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DEFENSE SYSTEMS MANAGEMENT COLLEGE

STUDY TITLE: USING COST ANALYSIS TO HELP BREAK THE OVERRUN HABIT

STUDY PROJECT GOALS: To present a teaching paper in briefing/narrative format which identifies reasons for cost overruns and shows how the cost analysis community can work with the program manager to prevent cost problems.

STUDY REPORT ABSTRACT:

This report is a treatise on cost analysis and cost management intended primarily to orient personnel unfamiliar with them. Major factors contributing to program cost problems are highlighted. The results of several studies on cost growth are portrayed, and several recommendations are made for controlling cost. Cost analysis responsibilities and methodology are presented in detail and examples are used. Parametric methodology is emphasized heavily as this is the government's primary technique. Analytical and institutional problems are discussed and on-going research to solve them is described. The report closes with a discussion of how the program director and cost analysts can work together to help break the overrun habit.

SUBJECT DESCRIPTORS: COST ANALYSIS, PARAMETRIC, COST MANAGEMENT

NAME, RANK, SERVICE	CLASS	DATE
RICHARD W. GRIMM, MAJOR, USAF	PMC 77-1	May 1977

EXECUTIVE SUMMARY

Right now we cannot find one major program in DOD that has ever come in for the original cost estimate. Three prominent reasons are that frequently we don't know the costs of previous programs, we don't know how to evaluate cost very well early in a program, and we don't know how to control or influence cost.

Costs grow for a variety of reasons, but most growth (85%) is due to requirements and specification changes, while 15% is due to poor cost estimating. This requires a program manager to challenge requirements continually and do enough conceptual and validation work to reduce risk to an acceptable level. The increased program definition will then enable costs to be estimated with higher confidence.

The program manager should use the cost analysis community frequently. The independent cost analysis process has improved estimating in recent years. Methodology incorporating parametric relationships, analogies, build-up techniques and historical data can be used to bound the range of most probable costs.

Cost analysis methodology is still evolving, and software estimating is getting increased attention. The best estimates are derived from detailed program definition and an intimate understanding of the program by the analyst.

TABLE OF CONTENTS

USING COST ANALYSIS TO BREAK THE COST OVERRUN HABIT

I would like for you to imagine for just a moment that you are the new Secretary of Defense making your initial visit to the Congress to defend the fiscal 1978 defense RDT&E budget. Senator Proxmire begins the questioning.

"Would you say, Mr. Secretary, that the Department of Defense uses innovative techniques and works hard at program management?"

"Yes, Senator," you answer proudly. "The department systematically develops the best talent it can to manage programs and guard the taxpayers' dollar."

"Will you tell me, then," the Senator rejoins, "why I cannot find a single manager of a major program in your department who has ever brought his program in for the original cost estimate?"

You have been trapped, because the horrible fact is that the Senator's allegation is true. You respond weakly with some statement to the effect that many of the causes are outside the program managers' control, but you resolve that our performance must improve.

This anecdote is to enable us to focus on identifying the cost growth problem and then suggest ways in which the cost analysis communities can work with the program manager to accomplish what I call "breaking the overrun habit."

COST ANALYSIS IN WEAPON SYSTEM ACQUISITION PROBLEMS

The problem has at least three facets. First, frequently we don't know what the costs are of systems bought in the past. Do you realize that one year after a program office is disbanded, its records are sent to federal storage, which is practically the same as destroying them. The final system configuration may have changed significantly from the last one costed, and no program office folding up its tents ever has the time to cost a "fait accompli". So all we are left with is a trail of estimates, not actuals, for a system that is not the same as the one we bought. Second, we have trouble evaluating cost, especially at the Required Operation Capability (ROC) or Conceptual stage. Cost analysis has not progressed to the place where models are waiting on the shelf completely verified, documented and universally applicable. Third, we don't know very well how to control or influence cost. We have been designing to a performance specification for decades and have mastered this procedure generally. Now, however, design-to-cost and fiscal constraints have pulled the rug out from under us, and our engineers and program managers are literally returning to the drawing boards.

COST ANALYSIS IN WEAPON SYSTEM ACQUISITION

PROBLEMS: FREQUENTLY -

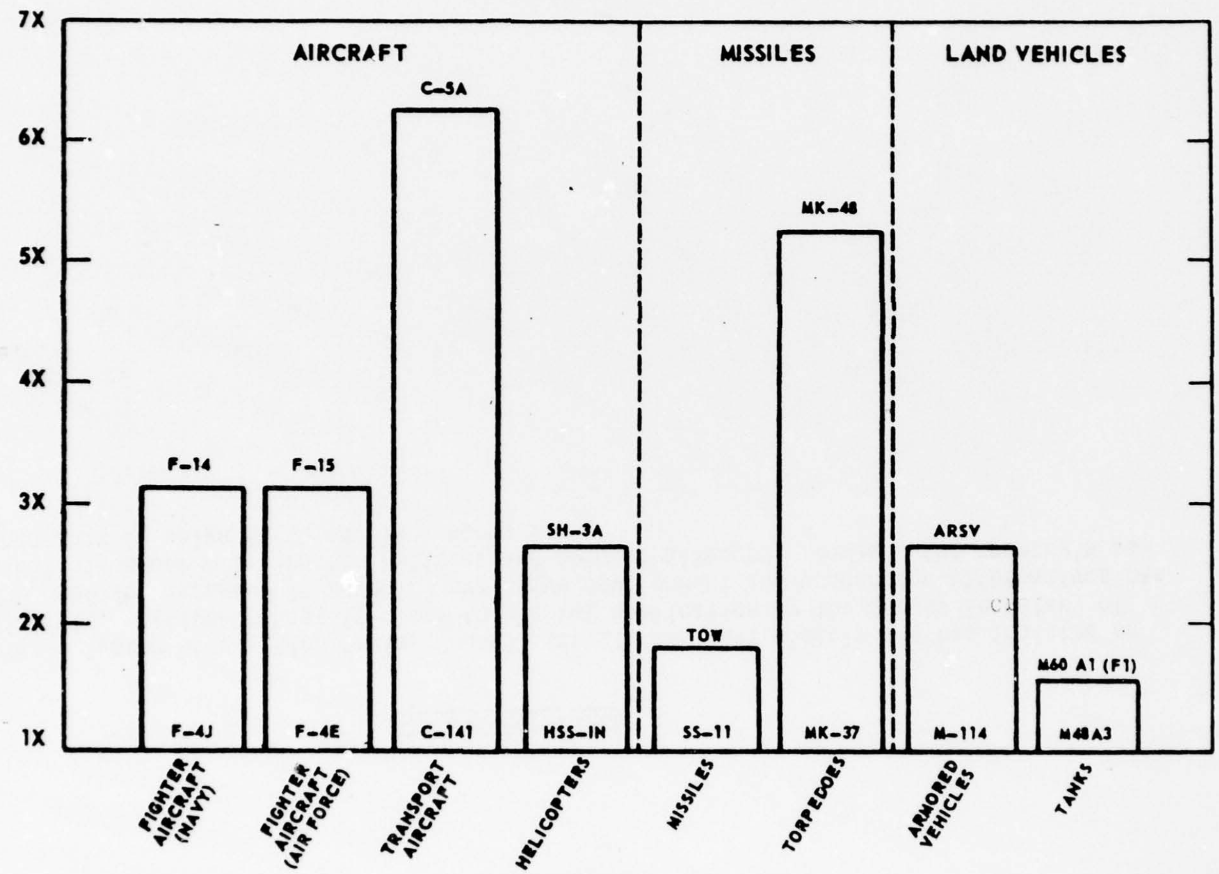
1. WE DON'T KNOW WHAT THE COSTS OF PAST ACQUISITIONS ARE.
2. WE DON'T KNOW HOW TO EVALUATE COST.
3. WE DON'T KNOW HOW TO CONTROL OR INFLUENCE COST.

REPRESENTATIVE COST DIFFERENCES BETWEEN PAIRS OF SUCCESSIVE WEAPON SYSTEMS 1960-1970'S (CONSTANT YEAR DOLLARS)

One doesn't have to look very far to be motivated to attack these problems. The fact of rising system costs and relatively constant defense spending power does give rise to the haunting specter of one plane, one ship or one tank in the 2030's.

FIGURE 1

REPRESENTATIVE COST DIFFERENCES BETWEEN PAIRS OF SUCCESSIVE WEAPON SYSTEMS 1960–1970'S [1]
(CONSTANT YEAR DOLLARS)

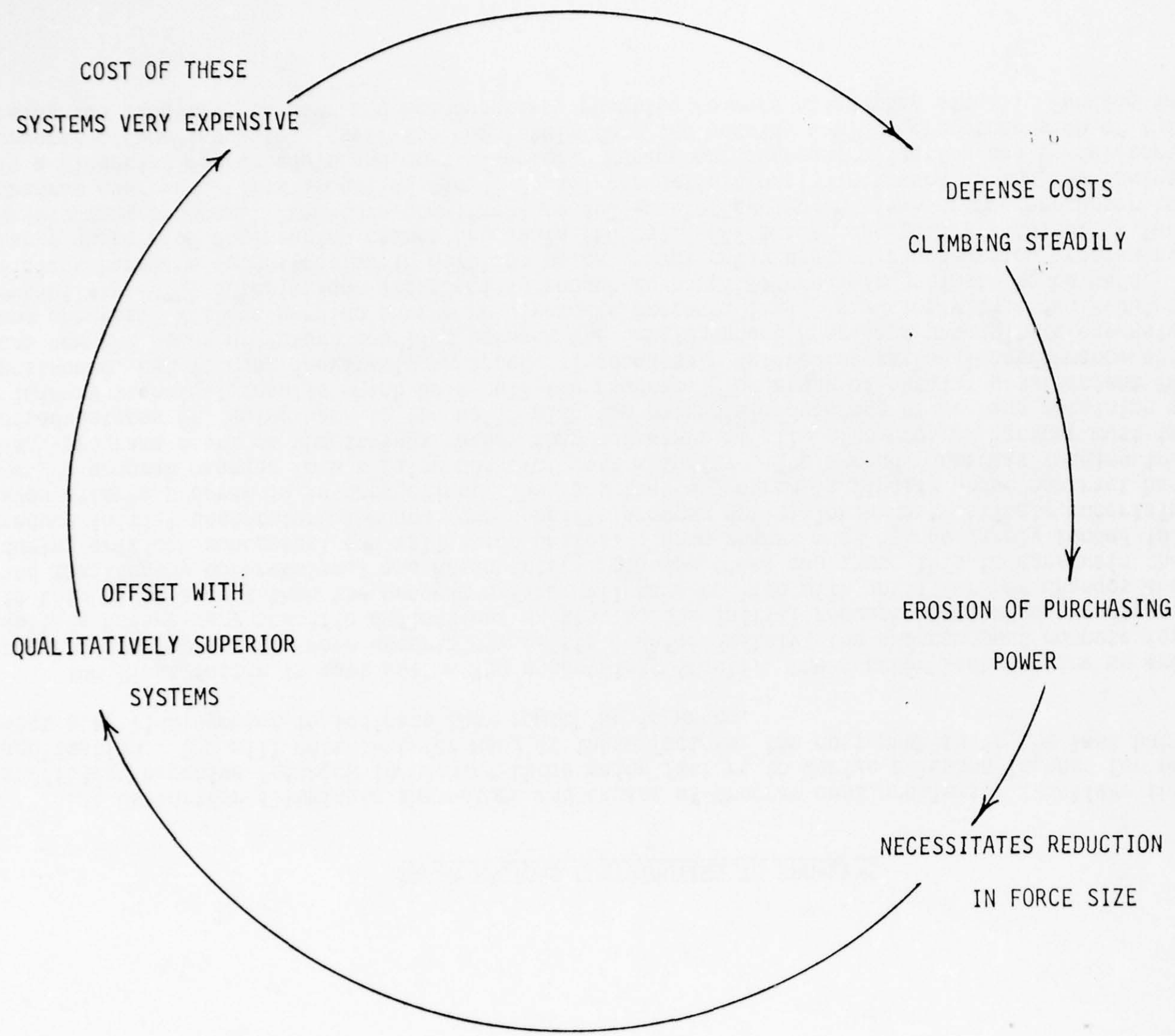


[1] Source: Data provided to GAO by the U.S. Army, Navy and Air Force.

THE VICIOUS CIRCLE

The Defense System Acquisition Review Council scrutinizes cost closely and has insisted on higher credibility. Design-to-Cost is close to blanket application by the Deputy Secretary of Defense. The need for accuracy in weighing expensive development and production alternatives has become critical since our military capabilities are being challenged. Indeed, the country's security demands that we solve these problems soon.

THE VICIOUS CIRCLE



MAJOR FACTORS CONTRIBUTING TO PROBLEMS

Let us further illuminate the nature and causes of program cost problems. I believe there is sufficient negative feedback in each of these major factors to derive a lesson learned for positive application. You will note that for many of these factors, the cost problem is the last but perhaps most startling symptom to indicate that something is wrong.

The first factor is cost estimating uncertainty itself. The farther back in time we are from program completion, the more uncertainty exists. Unfortunately, the program must compete for budget dollars before very specific definitions exists, so the initial request has the most uncertainty. It is this first budget that the program office will have to live with until further changes are submitted, and the lengthy congressional and headquarters response times can cause this to constrain the program during critical conceptual and validation phases. These phases must be adequately funded in order to reduce initial uncertainty through more specific program definition. Cost estimate uncertainty exists, even after a program is in production. The fact that a program is finally under contract has lulled many a program manager into a false sense of cost security. The second factor is funding insufficiency. Many programs start on shoestrings rather than not start at all. The program manager must trade the disadvantages of "going back to the well" with the potential advantage of perhaps obtaining some preliminary technical results which help sell the program. The agony of obtaining sufficient funds can be postponed, but it must inevitably be faced. Inadequately defined operational performance objectives can sow the seeds of future conflict between the developer and user, and precipitate expensive redesign and changes. Without harping on the requirements process, I will say simply that few Required Operational Capability (ROC) descriptions are specific enough to permit a credible estimate to be made. An insufficient hardware demonstration in development can practically destroy a production program by generating large numbers of engineering change proposals (ECP's). ECP's are more easily handled, by far, in the development program. Premature commitment to full-scale development is a common precursor to development program overruns. This is called "let's do all the definitional dirty work in the FSD contract," which is a blueprint for schedule and cost disaster. Management overcentralization can be deleterious if the program office insulates itself too completely from the outside world. The other side of this coin is being too sensitive to user and headquarters, reacting to more noise than signal. Funding inefficiency

MAJOR FACTORS CONTRIBUTING TO PROBLEMS
(Continued)

is best exemplified by fiscal constraints which prevent the money from being there when the effort requires it. Any constraints which cause an abnormally slow buildup or sudden bulge in manpower may inadvertently cause significant schedule slips. Noting excessive technical documentation is like complaining about the weather. The thing to do about it is to ask only for what you are sure you will use. The fact that this is a universal contractor complaint must make some impression on us. Problems in management control systems may prevent both the contractor and the government from ascertaining accomplished work versus planned work and actual costs. This may permit an incipient problem to grow undetected during critical periods when prompt management action might have been taken. Program management quality insufficiency goes without saying - why else are we at the DSMC? Contracting inflexibility can cause a program cost-grief from the beginning in choosing a contractor and in time lags caused by tardy RFP's and source selections. We are still having trouble with finding the right incentives to motivate contractors to build in reliability and reduce production cost. Premature commitment to production superimposes unresolved development problems over the production process. ECP's, again, can cause amazing growth at this supposedly well-defined stage of the program.

MAJOR FACTORS CONTRIBUTING TO PROBLEMS

- COST ESTIMATING UNRELIABILITY
- FUNDING INSUFFICIENCY
- INADEQUATE DEFINITION OF OPERATIONAL PERFORMANCE OBJECTIVES
- INSUFFICIENT HARDWARE DEMONSTRATION
- PREMATURE COMMITMENT TO SYSTEM DEVELOPMENT
- MANAGEMENT OVERCENTRALIZATION
- FUNDING INEFFICIENCY
- EXCESSIVE TECHNICAL DOCUMENTATION
- PROBLEMS IN MANAGEMENT CONTROL SYSTEMS
- PROGRAM MANAGEMENT QUALITY INSUFFICIENCY
- CONTRACTING METHODS INFLEXIBILITY
- PREMATURE COMMITMENT TO PRODUCTION

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ESD STUDY

This chart depicts average percent changes due to all causes, including government generated ECP's, in 60 Electronic System Division contracts. It shows that no matter what type of contract or what kind of product, the direction is monotonic increasing. In the aggregate, we negotiate the winner down 14%, the outcome is nearly 20% higher than his original bid, and the contract grows by nearly 40%. Who are we trying to kid by doing business this way? Ourselves? We pay some very highly motivated people to be tough negotiators, but the result appears to be that the contract will simply grow more. Of course, if we didn't have tough negotiators, then we might be gouged and pay twice what we should. Our goal should be to negotiate a realistic cost that challenges the contractor to be efficient -- not the lowest price we can get necessarily. It would be wiser not to write the procurement and contracting officer's effectiveness report based on the percent reduction from the proposal.

ESD STUDY

AVERAGE PERCENT CHANGE IN COST OF 60 CONTRACTS

	FPIF	CPIF	CPFF	AGGREG ALL CONTR	PROD	HDWE DEV	SFTWE	O&M	OTHER
Prop to Contract Award	-15.8	- 9.3	-15.5	-13.9	-13.5	- 7.0	- 9.8	-22.2	-13.5
Prop to Contract Completion	+15.2	+28.8	+15.9	+19.8	+34.6	+21.5	+29.3	+ 7.3	+16.9
Contract Award to Completion	+38.8	+42.0	+40.8	+39.2	+55.7	+30.7	+43.4	+37.9	+35.1

RICHARD W. GRIMM, MAJOR, USAF PMC 77-1 May 1977

COMPUTER PROGRAMMING - (SOFTWARE)

You can readily see why software development programs offer the manager and cost analyst some of his severest challenges. Sizing, or lines of code, is the best explainer of software cost. How can you tell from these bids who is telling the truth? A has the most realistic cost per instruction, but his sizing may be very understated. These bids may in fact show what the contractor thinks it takes to win, not what it takes to do the job. The sleeper in all of this could be E. If he already has 650,000 instructions on the shelf, his bid may be pretty accurate, but how do we know what is on his shelf?

COMPUTER PROGRAMMING - (SOFTWARE)

XXX PROGRAM

CONTRACTOR	SIZING	DOLLARS
A	153,000	$ 2,800,000
B	282,000	$ 2,500,000
C	400,000	$ 4,600,000
D	735,000	$ 4,500,000
E	766,000	$ 2,100,000

RESPONSE TO:

(1) SAME SPECIFICATION

(2) SAME WORK STATEMENT

(3) BUILDING BLOCK

CAUSES AND EXTENT OF COST GROWTH

Back in the early 1970's, the Air Force undertook a major study of system cost called Project ACE (Acquisition Cost Evaluation). Their findings supported the twelve reasons we enumerated previously, although they found that isolating reasons for growth wasn't easy. One significant finding was that whereas outcomes in the 1950's averaged 53% cost growth, outcomes in the 1960's averaged 40%, a 25% performance improvement. At least we are improving, but I question whether 40% is good enough. Changes in scope appeared to be the major bugaboo. While the limitations of the program director's control over scope changes are well known and worrisome, this does show that his attention to requirements is critical, especially at the outset.

<u>CAUSES AND EXTENT OF COST GROWTH</u>

- <u>CAUSES OF COST ESCALATION NOT OBVIOUS</u>

  BAD ESTIMATING

  BAD COST CONTROL

  UNDEFINED AND CHANGING REQUIREMENTS

  ETCETERA

- <u>COST GROWTH AVERAGE</u>: <u>40%</u>

  HOWEVER - 1970 ACTUAL OUTCOMES SIGNIFICANTLY CLOSER TO PROGRAMMED OUTCOMES THAN IN 1960 - <u>25%</u> BETTER

- MOST COST GROWTH AND PERFORMANCE CHARACTERISTIC FAULTS APPEAR AS CHANGES IN <u>SCOPE</u> - I.E., OUTSIDE OF SPD'S CONTROL

WHAT MAKES COST GROW?

Rand's cost analysis capabilities were at their zenith in the early 70's, so the government sought their opinions and research on cost growth. While specification changes clearly denote requirements changes, schedule changes can be either technically or fiscally related. It is interesting to note that they were able to quantify the causes of growth to be 80-85% spec and schedule and 15-20% cost estimating. Another government think tank, ANSER, made the qualitative findings that supported RAND and Project ACE. In addition, they made a very interesting allegation which goes hand in glove with requirements growth: the size of the overrun is directly related to how hard we press the state of the art to meet these requirements.

WHAT MAKES COST GROW?

- RAND TESTIMONY - 'SENATE ARMED SERVICES COMMITTEE - DECEMBER 1971'

  COST GROWTH

50%	DUE TO SPECIFICATION CHANGES
30 - 35%	DUE TO SCHEDULE CHANGES
15 - 20%	DUE TO COST ESTIMATE

- ANSER

  "BY FAR - GREATEST CAUSE OF COST GROWTH IS REQUIREMENTS UNCERTAINTIES."

  "SIZE OF COST OVERRUNS DIRECTLY RELATED TO THE DEGREE OF TECHNOLOGY ADVANCE SOUGHT."

COST GROWTH - ESD STYLE

The ACE, RAND and ANSER work prompted us to take a closer look at our own Electronics Systems Division. Not too surprisingly, our percentages followed the same 85-15 split as RAND observed. The technical growth was partitioned to show growth in technical effort to meet requirements versus the requirements growth itself. The cost community could justifiably use this slide to say, "Don't look at me for dramatic improvements in this process," but it is of no consolation. We are in this together and must improve in all aspects. The greatest potential yield appears to be in requirements and specifications.

COST GROWTH - ESD STYLE

- WITHOUT DISPUTING NEED FOR BETTER ESTIMATING, DATA SUGGEST THAT ESTIMATING REFORMS ARE NOT LIKELY TO REDUCE UNDERLYING PROBLEMS.

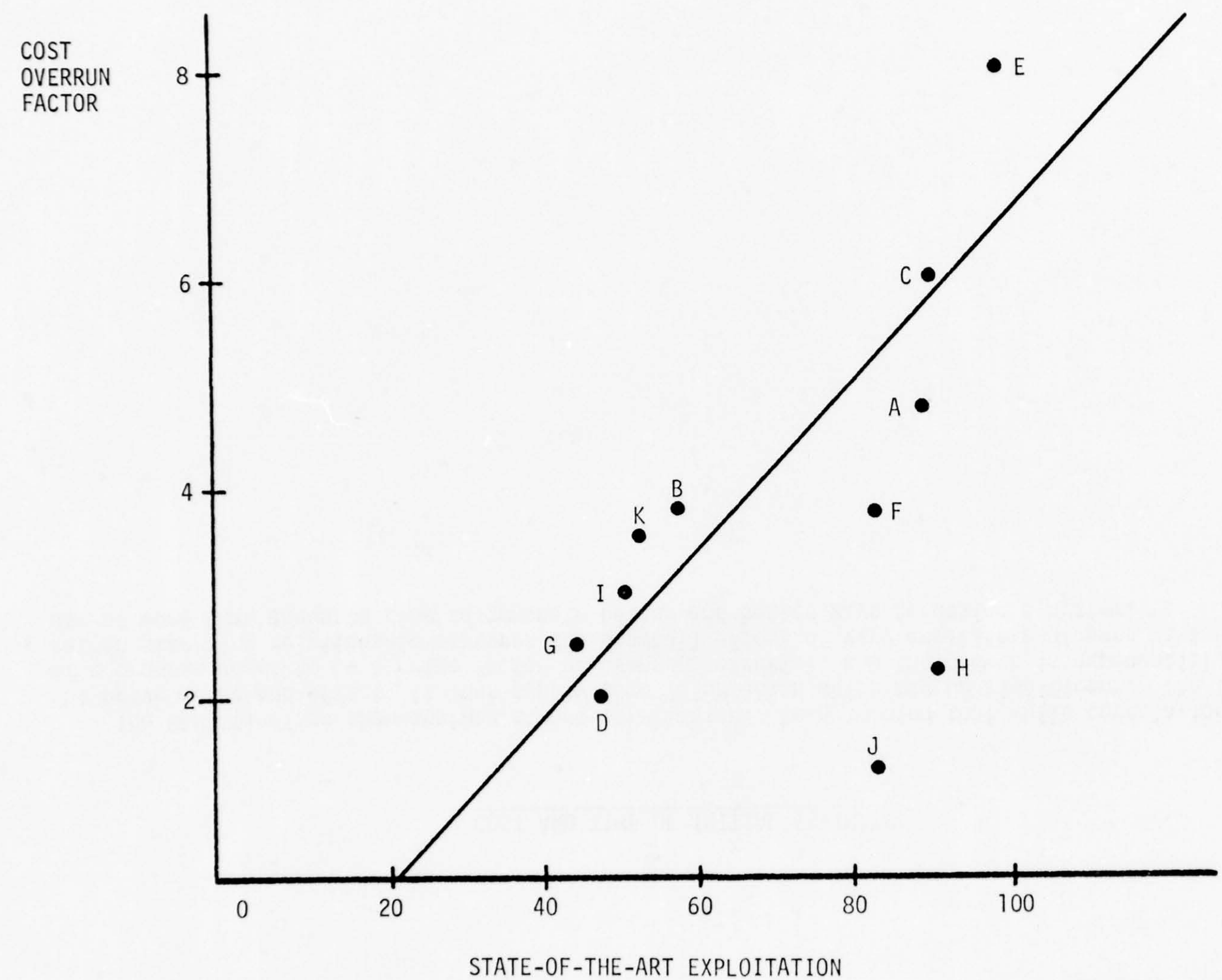
- ESD STUDY

CHANGES IN REQUIREMENTS	= 54%
INCREASES IN ENGINEERING AND TECHNICAL EFFORT TO SATISFY SYSTEM REQUIREMENTS	= 32%
CORRECTION TO OR REFINEMENT OF ESTIMATES	= 14%

CORRELATION OF COST OVERRUNS WITH STATE OF THE ART

The ANSER folks did a little work with surveying experts to assess the degree to which various programs pressed the state of the art, e.g., what percent of each system was not proven on the shelf hardware. The trend is obvious, but the scatter is very wide. I suppose the manager could say, "I will exploit about 80% and with good management, my outcome will be like J's (program will be accomplished at less than twice the original estimate). Maybe so, but the E and C outcomes are as likely (6 and 8 times original cost).

CORRELATION OF COST OVERRUNS
WITH STATE OF THE ART

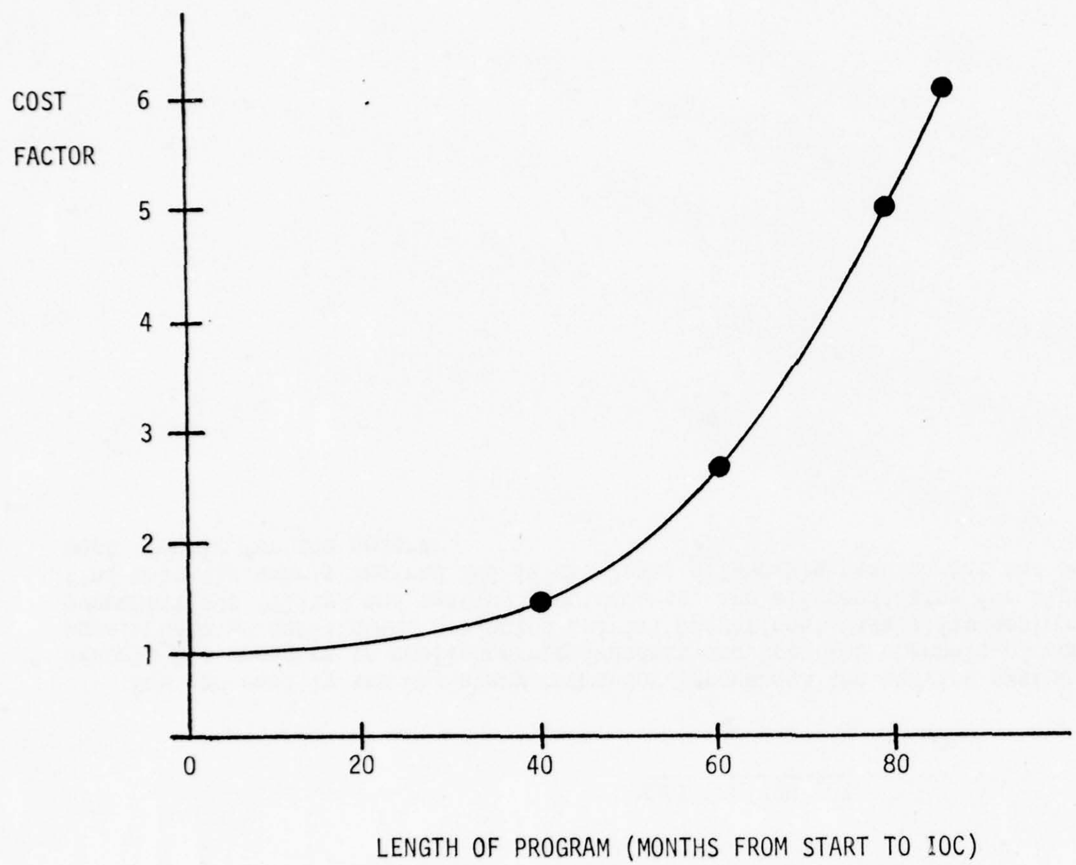


SOURCE: ANSER

COST AND TIME OF INITIAL ESTIMATE

The RAND findings show another strong correlation. Keep in mind that while correlation does not prove cause and effect, it does supply some information which may be significant. The length of a program seems to be a prime factor of overrun potential, and the growth is exponential. This rather startling relationship captures the snowball effect of very creative engineers making active use of more than adequate time to generate better and better ways to design a system.

COST AND TIME OF INITIAL ESTIMATE



SOURCE: RAND

WHAT CAN YOU DO?

You can readily see why every commander throughout the service system acquisition commands exhorts his managers to challenge requirements and keep the channels of communication to the user open. Data we don't need, projected Initial Operational Capability deployments too soon and overambitious "ility" and testing requirements, are all candidates for close scrutiny. At ESD, I find that the user's desired IOC is the least defendable requirement and yet it probably causes the most trouble for the program.

WHAT CAN YOU DO?

- **CHALLENGE REQUIREMENTS**
    - CORE CONFIGURATION
    - USER - SPO DIALOGUE
    - DATA BANKS
    - SCHEDULES
    - - ILITIES
    - TEST

EXAMPLE OF REQUIREMENTS CHALLENGING

You can challenge requirements. I have no axe to grind with avionics, although I am concerned with their cost growth. Here is an example of some avionics requirements challenging that I borrowed from someone who did. It is possible that a rationale such as this may have had some impact on our A-10 and F-16 system engineering.

EXAMPLE OF REQUIREMENTS CHALLENGING

IS THE COST EXPLOSION UNAVOIDABLE?

AVIONICS

ESSENTIAL?

RADAR FIRE CONTROL, INERTIAL, COMPUTERS, HUD, DATA LINKS, INTERNAL JAMMERS, AUTOPILOT, LORAN, SECURE VOICE, SECURE IFF, ETCETERA

THE MOST SUCCESSFUL MIG - KILLER TODAY HAS NONE OF THE ABOVE - NOR DOES THE MIG.

EXCESSIVE COST COMPLEXITY

	MILITARY		COMMERCIAL
RADAR	$ 1 M	VS	$ 4 - 40,000
RADIO	$ 15,000	VS	$ 1300
TACAN	$ 28,000	VS	$ 1500

COMPLEXITY DEGRADES PERFORMANCE - AIRLINE RADARS HAVE 800 HR MTBF; MILITARY RADARS HAVE 5 - 10 HRS - ONE FIRST LINE SYSTEM HAS 47 MIN.

MANAGEMENT TECHNIQUES

The program manager has two effective strategies at his disposal to fight the historical trends. He should attempt to keep the government's commitment to a minimum until risk can be reduced to an acceptable level. This is what a validation phase is for -- use it. Secondly, budget your program to account sufficiently for escalation, plan on your fixed price incentive contract going to ceiling, and do not fail to incorporate a management reserve implicitly in your funding request. Do not earmark a percentage as management reserve or you will lose it. Bury it in the work breakdown structure and remember how much you buried and where.

MANAGEMENT TECHNIQUES

- MINI GOVERNMENT COMMITMENT

  IN FRONT END OF PROGRAMS -

  UNTIL RISK REDUCED TO AN

  ACCEPTABLE LEVEL

- FUND/BUDGET TO "BEST ESTIMATE"

  - MANAGEMENT RESERVE
  - CEILING
  - ESCALATION

RESPONSIBILITIES

How can the program manager best use the cost analysis community to help solve the problems we have identified? A look at cost analysis responsibilities may shed some light on this question. Most of these functions are common to the cost organizations within the Air Force Systems Command Acquisition Divisions, namely Aeronautical and Electronic Systems Divisions, Space and Missile Systems Organization and the Armament Development and Test Center. They add up, simply, to providing estimating support during the program lifetime, assisting with analysis of contractor cost performance reporting and conducting independent cost analyses in support of DSARC decisions on the program. The last item is a creation of Electronic Systems Division and is aimed at a realistic implementation of life cycle cost (and design-to-cost) considerations. The committee is composed of logistics, procurement and comptroller personnel who assist program offices in their implementation of life cycle cost. This usually takes the form of recommending contractual incentives aimed at improving operating and support costs, and promoting design-to-life cycle cost awareness.

RESPONSIBILITIES

PROVIDE COST ESTIMATING SUPPORT TO LINE ORGANIZATIONS/OTHER AGENCIES

MONITOR AND ANALYZE COST/SCHEDULE CONTROLS SYSTEM CRITERIA & REPORTING

MAINTAIN COST DATA LIBRARY

DEVELOP NEW ESTIMATING TECHNIQUES AND RELATIONSHIPS

SUPPORT SOURCE SELECTIONS

CONDUCT AND MONITOR INDEPENDENT COST ANALYSES (ICA)

SUPPORT AND CHAIR THE LIFE CYCLE COST REVIEW AND ADVISORY COMMITTEE

INDEPENDENT COST ANALYSES

Independent Cost Analyses, a special kind of cost estimate, are a product of the 1970's. They were instituted to improve the credibility of estimates going to OSD. Notice that the ICA is not the program office estimate but rather is a reasonableness check on the program office estimate. The motivation for making the Comptroller responsible for ICA's was the removal of estimating from advocacy channels and their inevitable political ramifications.

INDEPENDENT COST ANALYSES

DEFINITION:

A TEST OF REASONABLENESS OF THE OFFICIAL PROGRAM COST ESTIMATES BY A TEAM ORGANIZATIONALLY SEPARATE FROM THE PROGRAM OFFICE

OBJECTIVE:

TO IMPROVE AIR FORCE COST INPUT TO DSARC BY PRODUCING AN ESTIMATE OF THE MOST PROBABLE COST FOR THE SYSTEM'S LIFE CYCLE

TOWARD THIS OBJECTIVE THE AIR FORCE HAS:

The Air Force has routinized ICA administration and formalized procedures through AFR 173-11. More importantly, they realized that a powerful inducement to getting the best possible product was to advertise that some of the highest officials in the Air Force would be briefed personally by the team chief on his way to the OSD Cost Analysis Improvement Group (CAIG). Since the OSD CAIG also submits its own estimate to the DSARC, you can see that the DSARC receives three estimates: one from the program office, a service ICA and an OSD CAIG ICA. A third significant action was the encouraging of more user command and logistics involvement in the process and some major initiatives in O&S data retrieval and estimating.

COST STUDIES (FORMERLY INDEPENDENT COST ESTIMATES)

At ESD, we call an estimate that is not an ICA a cost study. This happened because the Commander wanted the program manager to feel and be responsible for its quality and use. The term independent cost estimate (ICE) was responsible, in his view, for too many managers feeling that the estimate was "the comptrollers thing". The ICE designation is quite common elsewhere, however, and it is meant simply to designate an effort done outside the program office. The team is led by a cost analyst from the comptroller. Key team members come from the program office's program control and engineering divisions. These PO personnel provide program definition, documentation of all costs incurred to date and all relevant future considerations. If the effort is to establish the PO estimate in the first place, the PO may assist in the derivation of costs and should use and modify the estimate for budgeting, management, etc. Once done, keeping it current is difficult, but it must be done to insure the program's economic health. In the special case of an estimate to be used as a reasonableness check on proposals submitted to a source selection, the PO must not modify it unless a program change is the reason.

TOWARD THE OBJECTIVE THE AIR FORCE HAS:

- DEVELOPED AFR 173-11
  - AF COST ANALYSIS PROGRAM
- SET UP A HIGH LEVEL REVIEW CYCLE FOR ICA'S
  - AF CAIG AND AF COMPTROLLER
  - SAFFM AND SECAF
  - OSD CAIG
- INITIATED EFFORTS TO IMPROVE O&S ESTIMATING
  - EXPANDED TECHNIQUES
  - INVOLVEMENT OF APPROPRIATE COMMANDS

COST STUDY TEAM RESPONSIBILITIES TO PROGRAM OFFICES

TO PROVIDE:

1. ENTRANCE BRIEFING TO THE PROGRAM MANAGER DETAILING THE STUDY PLAN AND DATA REQUIREMENTS.

2. A THOROUGH BRIEFING OF THE ESTIMATE TO THE PROGRAM MANAGER TO INSURE A COMPLETE UNDERSTANDING OF METHODS, ASSUMPTIONS, RESULTS.

3. THE MOST ACCURATE ESTIMATE POSSIBLE, EMPLOYING REASONABLENESS CHECKS AND COMPARISONS.

INDEPENDENT COST ANALYSES

The main difference with an ICA is that costs are derived by cost analysis, the estimate is used as a reasonableness check and it is not intended for PO adoption and modification. The PO certainly may make use of the findings, however, in shaping their attitudes about where the program is going.

INDEPENDENT COST ANALYSES

1. COMPTROLLER - PROGRAM OFFICE TEAM APPROACH LED BY COMPTROLLER.
2. PO TECHNICAL INPUTS ONLY. COSTS ARE DERIVED INDEPENDENTLY.
3. AT A MINIMUM, A PARAMETRIC APPROACH IS REQUIRED.
4. USUALLY DONE FOR DSARC LEVEL PROGRAMS AT MAJOR MILESTONES, ENCOMPASSING THE LIFE CYCLE OF THE PROGRAM.
5. ESTIMATE NOT SUBJECT TO PO MODIFICATION.

COST STUDY TEAM RESPONSIBILITIES TO PROGRAM OFFICES

Effective communication is mandatory especially at the beginning and the end of the effort. If the program manager is unaware of the study or feels it is unimportant, then his people will be unavailable to supply the necessary definitions. Thorough entrance and exit briefings are necessary and documentation must follow.

COST STUDIES (FORMERLY INDEPENDENT COST ESTIMATES)

1. COMPTROLLER - PROGRAM OFFICE TEAM APPROACH LED BY ACC.
2. PO TECHNICAL AND COST INPUTS.
3. OUTPUT PROVIDES INFORMATION TO PO FOR THEIR USE IN BUDGETING, PROGRAM MANAGEMENT, ETC.
4. CAN BE DONE ON ANY PORTION OF A PROGRAM AT ANY TIME IN THE LIFE CYCLE. IT SHOULD BE KEPT CURRENT.
5. WHEN USED FOR SOURCE SELECTION, IT IS NOT SUBJECT TO PO MODIFICATION UNLESS THE PROGRAM CHANGES.

PROGRAM OFFICE RESPONSIBILITIES TO COST STUDIES

When your friendly cost analyst arrives, he will probably ask for details on the twenty-three inputs I have listed here. The demands on PO personnel are great to both supply the information and keep everything else going. The quality of the information rendered, however, will be the most important determinant of estimate realism and accuracy.

PROGRAM OFFICE RESPONSIBILITIES TO COST STUDIES

TO PROVIDE

1. PURPOSE, SCOPE, DUE-DATE
2. SCHEDULES AND QUANTITIES
3. TECHNICAL DESCRIPTION OF HARDWARE
   - A. PHYSICAL ATTRIBUTES
   - B. CLOSEST ANALOGY
   - C. ENGINEERING COMPLEXITY
   - D. TESTING PROGRAM
   - E. ENGINEERING CHANGE LEVEL EXPECTED
   - F. HARDENING REQUIREMENTS
   - G. GFE DESCRIPTION
4. SOFTWARE DESCRIPTION
   - A. FUNCTIONS PERFORMED
   - B. NUMBER OF INSTRUCTIONS AND TYPE
   - C. TESTING PROGRAM

PROGRAM OFFICE RESPONSIBILITIES TO COST STUDIES
(Continued)

PO INPUTS TO COST STUDIES (CONTD)

5. CONTRACTOR/SUBCONTRACTOR RELATIONSHIP EXPECTED AND TYPE OF CONTRACT
6. EXPECTED FISCAL FUNDING SPREAD (PERCENTAGES) AND PROGRAM BASE YEAR
7. PROGRAM ESCALATION RATES AND EXPENDITURE PROFILE
8. RELEVANT CONTRACTUAL DATA ON COSTS INCURRED TO DATE
9. RESULTS OF ANY CONTRACT DEFINITION PHASE STUDIES
10. MILCON PROGRAM
11. SUPPORT REQUIREMENTS, I.E., GOVERNMENT TEST, MITRE, CONSULTANT, ETC.
12. PROGRAM OFFICE ENGINEERING ESTIMATES FOR POST-ESTIMATING COMPARISON
13. BASING AND MAINTENANCE CONCEPTS
14. EXPECTED MTBF
15. EXPECTED LIFE CYCLE TIME HORIZON

963

ICA METHODOLOGY

Government cost analysis methodology is comprised of these four techniques. All but the third can be used as the program begins and proceeds through development. The engineering or build-up methodology relies on recurring cost data from development or pre-production prototypes, which makes it an appropriate technique only for production. The cost analysis community does not as a rule get into labor, material and overhead estimating, which differentiates it from our industry counterparts. The pricing analysts resident in government procurement divisions do examine and critique these data as submitted by contractors.

ICA METHODOLOGY

GUIDING PHILOSOPHY: METHODOLOGY IS DETERMINED BY THE AVAILABILITY OF PERTINENT PROGRAM DATA. THIS IN TURN IS USUALLY DICTATED BY THE PARTICULAR PHASE THE PROGRAM IS IN.

TECHNIQUES:

- PARAMETRIC
- ANALOGY
- ENGINEERING (BUILD-UP)
- HISTORICAL DATA

PARAMETRIC TECHNIQUE

The technique most commonly used by far is the parametric. Why do you suppose the government emphasizes parametrics so heavily while industry uses industrial engineering estimates almost exclusively? Why has the OSD Cost Analysis Improvement Group (CAIG) insisted that every ICA employ at least a parametric estimate, if not others? The reason is two-fold. Parametrics don't forget the past disasters (and successes) in their data bases. They are not inherently optimistic or pessimistic. Have you ever seen an engineering estimate for a development program that didn't assume in the euphoria of getting started, that most things would go right? Secondly, it is wise for the government to exploit a technique not widely used by industry in hopes of shedding the most light on a decision alternative since program office estimates usually reflect contractor inputs. This first cost estimating relationship (CER) was a product of some of my work in the AF Avionics Laboratory. It is a useful relationship (F-16 radar competition) because it captures what all radar engineers ultimately are striving for: increased detection range. It also accounts for multi-mode and higher frequency radars being more expensive. The second CER is more design oriented and is the basic relationship of the RCA PRICE model, which is the state of the art in parametrics. It is a kind of smart cost per pound approach. Everyone knows a pound of large scale integrated circuitry costs more than a pound of semiconductors, so this is how the complexity factor adjusts the cost per pound. Since the government uses parametrics so frequently and since their use can be tricky, we will delve more deeply into the assets and liabilities of this technique.

PARAMETRIC TECHNIQUE

1. AIRBORNE FIRE CONTROL RADAR

   1st UNIT COST = F(DETECTION RANGE, MODE, FREQ. BAND)

2. ELECTRONICS COST = G(WEIGHT, COMPLEXITY) - PRICE MODEL

   GIVEN SCHEDULES, QUANTITIES, POWER, DENSITY.

PHILOSOPHY: PARAMETRICS ARE ESPECIALLY APPROPRIATE EARLY IN DEVELOPMENT WHEN TECHNICAL DETAILS ARE SKETCHY. THEY ASSUME THAT THE PROGRAM'S COST DRIVERS FOLLOW THE SAME PATTERN AS PREVIOUS SIMILAR HARDWARE PROGRAMS.

MODEL USE ENVIRONMENT

Probably one of the foremost guidelines for using parametrics is that government and contractor engineers should determine the inputs. No CER can overcome erroneous data. A model like PRICE is very demanding in its cross checks of input data from a variety of program aspects, but the reward is development and production estimates accurate usually within ten percent. The government has even begun asking for inputs in RFP's, but we have found this to be largely unsuccessful. It is better than nothing, but getting contractor information before the RFP is out is highly preferable.

MODEL USE ENVIRONMENT

PARAMETRIC TECHNIQUE CONTRIBUTING TO:

1. COST STUDIES
2. INDEPENDENT COST ANALYSIS
3. INDEPENDENT ESTIMATES INPUT TO SOURCE SELECTIONS

HOW USED:

1. DIALOGUE WITH ENGINEERS - SPO, MITRE, CONTRACTOR
2. VISITS WITH CONTRACTORS
3. INPUT SOLICITATIONS TO CONTRACTORS IN RFP^{S}

FEATURES & BENEFITS OF PARAMETRIC COST ESTIMATING

One of the greatest benefits of good parametric estimating is the rapid, inexpensive cost estimation of design alternatives. If design-to-cost is going to work, the realistic evaluation of paper designs must be done in the conceptual and validation phases. A good model has some cross checks built in to verify critical inputs. The use of a model can induce discipline and consistency to estimating.

FEATURES & BENEFITS OF PARAMETRIC COST ESTIMATING

- GENERATES REALISTIC DESIGN/COST TRADEOFFS INEXPENSIVELY
- OPERATES OVER BROAD RANGE OF APPLICATION WITH RAPID RESPONSE
- ALLOWS USAGE EARLY IN PROGRAMS
- COMPUTERIZED DATA GATHERING
- COVERS ALL PHASES THROUGH INTEGRATION & TEST COSTS
- CONTAINS INHERENT SELF-CHECKING CALIBRATION
- DISCIPLINED APPROACH TO ESTIMATING

HOW TO DO A COST ANALYSIS

A legitimate question at this point is how are good models and cost estimating relationships (CER's) developed. This is basically the scientific method applied to statistics on an engineering phenomenon. About 95% of the effort is usually involved in gathering data -- relevant cost histories and data on parameters on which the engineers say they expend significant effort. If the statistical data substantiate the engineering significance premises, the analyst is well on his way to developing a useful CER. If it takes too many variables (parameters) to explain system cost, the analyst will disaggregate the system into subsystems. For example, he might break a radar into transmitter, receiver, signal processor, antenna, control and display. There may be important technical efforts within these line replaceable units (LRU) that would be explainable by a variable unique to that LRU but which would be masked at the system level. He normalizes the data so that inflation is removed and learning is accounted for. The primary technique for testing hypothetical relationships is statistical linear regression. This involves explaining a dependent variable (cost) as a function of one or more independent variables by fitting a line or surface which minimizes sums of squared errors. The resulting CER is evaluated by how well it fits or explains the data, its engineering meaning and its predictive capability. Some well-known models which have done all this quite well are the DAPCA Airframe Model and the RAND Aircraft Engine Model. Their documentation is outstanding, an unusual trait of most models and CER's.

HOW TO DO A COST ANALYSIS

1. DEFINE THE PROBLEM AND OBJECTIVE: THE DECISION AND THE DECISION MAKER
2. ACQUIRE BACKGROUND: READ REPORTS, CONSULT EXPERTS TO ASCERTAIN SALIENT PARAMETERS, PHYSICAL LAWS, STATE-OF-THE-ART
3. SELECT AN APPROACH FOR THE PARAMETRIC COST ESTIMATE DEVELOPMENT: EXISTING MODEL, NEW MODEL, DISAGGREGATION
4. ACQUIRE DATA: PARAMETRIC, COST
5. NORMALIZE THE DATA: PRICE INDEX, LEARNING CURVE, COST/TECHNOLOGY INDEX, PARAMETER DEFINITION
6. DEVELOP HYPOTHESES: AGGREGATE DATA BASE, COST AND EXPLANATORY VARIABLES
7. IS REFINEMENT NEEDED? MISSING DATA?
8. DEVELOP THE COST ESTIMATING RELATIONSHIPS: REGRESSION (STEPWISE, SIMPLE, RIDGE)
9. EVALUATE THE CERs: R^2, STD ERROR, ACTUAL/ESTIMATE, ACTUAL - ESTIMATE/ACTUAL, ENGINEERING DESIGN MEANING, PREDICTIVE CAPABILITY
10. PREPARE THE COST ESTIMATE
11. DOCUMENT THE MODEL: THE PROBLEM + OBJECTIVE, THE DATA, LIMITATIONS OF USE, ALTERNATIVE MODELS
12. MODIFY EXISTING COST ESTIMATING MODELS
13. DISAGGREGATION OF THE SYSTEM: WHEN DATA MAKES POSSIBLE, WHEN THERE ARE MANY INDEPENDENT VARIABLES
14. AGGREGATION OF COMPONENT COSTS

FIRE CONTROL RADAR PRODUCTION COST

(100TH UNIT COST IN 1970 DOLLARS)

Here is an example of a CER developed in the early 1970's at the AF Avionics Laboratory. Twenty-nine previously produced radars constituted the sample. The variables were suggested by electronics engineers and statistical t-tests bore out their significance. The R^2 or coefficient of determination is acceptable, i.e., the parameters explain 80% of the variability in cost. The standard error gives cause for concern -- the uncertainty band around the prediction is higher than that desired. A logarithmic (or multiplicative) model is used since percent changes in cost depend proportionally on percent changes in radar parameters and the technical point of departure for the change.

FIRE CONTROL RADAR PRODUCTION COST

(100^{TH} UNIT COST IN 1970 DOLLARS)

$$\begin{aligned} \text{LN (COST)} = & -26.50772 + 4.08297 \text{ LN (ANTENNA GAIN)} \\ & + 5.89568 \text{ LN (RECEIVER SENSITIVITY)} \\ & - 0.41480 \text{ LN (PULSE REPETITION FREQUENCY)} \\ & + 0.37958 \text{ LN (PULSEWIDTH BANDWIDTH PRODUCT)} \end{aligned}$$

29 CASES

F - TEST SIGNIFICANT AT THE 0.001 LEVEL

COEFFICIENTS ARE SIGNIFICANT AT THE 0.025 LEVEL OR BETTER

$R^2 = .8028$

STD ERROR = .5088, BETWEEN - 40% AND + 66% OF PREDICTED

HINDSIGHT RADAR PRODUCTION COST PREDICTIONS

This shows how well (or poorly) the CER predicts costs in its own data base. I was somewhat apologetic about the average error until an electronics cost expert from the Institute for Defense Analyses told me the state of the art in radar prediction was 50% errors. Don't be too impressed with the AWG-9 prediction accuracy. Because the regression minimizes sums of squared errors, it is bound to generate coefficients which predict this highest-costing radar in the data base accurately. This CER became outmoded with the advent of radars which use very high pulse repetition frequencies to detect targets. In fact, that precipitated the CER development shown earlier which used detection range, multi-mode and frequency band as variables.

HINDSIGHT RADAR PRODUCTION COST PREDICTIONS

RADAR	AIRCRAFT	ACTUAL	PREDICTED	PERCENT ERROR
APQ-99	F-4B/C	80,000	104,311	30.4
APQ-113	F-111A	273,648	320,856	17.3
APQ-116	A-7A	48,807	53,505	9.6
APQ-120	F-4E	308,243	230,099	25.4
APQ-153	F-5E	38,790	28,308	27.0
APG-59	F-4J	761,191	703,582	7.6
APQ-126	A-7D	78,000	59,647	23.5
APQ-130	F-111D	1,010,201	568,997	43.7
AWG-9	F-14	1,916,653	1,991,684	3.9

AVERAGE ERROR = 37%

PARAMETRIC CER^{S}
PRINCIPLES AND APPLICATIONS

The principles and applications of electronics CER's are true generally. They should be sensitive to the changing state of the art. Witness what the use of integrated circuitry has done to trim the cost dramatically of hand-held computers. Cost per pound of electronics varies with the technology, as does the number of functions accomplished. Care must be used in performance oriented development CER's that if the brunt of the work is going toward reliability for some fixed state of the art, then MTBF should be included as an explanatory variable.

PARAMETRIC CER^S

PRINCIPLES AND APPLICATIONS

1. SENSITIVE TO PARAMETERS AFFECTED BY THE CHANGING STATE-OF-THE-ART

   EXAMPLES:

   A. WEIGHT AND VOLUME OF IC^S

   B. HIGH PRF RADARS

   C. AIRBORNE COMPUTERS

2. FOR A FIXED STATE-OF-THE-ART, CAPTURE COST OF INCREASED RELIABILITY

   EXAMPLE:

   MICRON INERTIAL

PRINCIPLES AND APPLICATIONS (cont)

Performance sensitivity is probably not enough in a CER since many designs can meet the same performance requirement. I am convinced that we should drive toward design sensitive CER's as early as possible, recognizing that performance CER's may be sufficiently accurate very early in the game. The more parameters in a CER, the more the likelihood that correlations between these variables will cause a distortion in regression coefficients. This is called multicollinearity, and it evidenced itself in the radar CER I showed you in the coefficient of receiver sensitivity. It caused my CER to double the cost of the Electronically Agile Radar when an air-to-air capability was being hypothesized, whereas a 50% hike should be a worst case. Hopefully, a CER should be robust enough to evaluate systems having parameters outside the range which created the CER.

PRINCIPLES AND APPLICATIONS (cont)

3. ABILITY TO DIFFERENTIATE BETWEEN DESIGNS AIMED AT THE SAME PERFORMANCE REQUIREMENT

   EXAMPLE:

   LASER MAVERICK SOURCE SELECTION

4. NOT OVERLY SENSITIVE TO CERTAIN PARAMETERS; MULTICOLLINEARITY PROBLEMS

   EXAMPLE:

   B-1 RADAR

5. ABILITY TO EVALUATE SYSTEMS HAVING PARAMETERS OUTSIDE THE RANGE WHICH CREATED THE CER^{S}.

   EXAMPLES:

   A. F-15 RADAR

   B. ADVANCED AIRBORNE COMMAND POST

CONCLUSION

In summary, parametrics are best early in the game. The challenge is to capture the cost drivers which have engineering meaning.

CONCLUSION

PARAMETRICS ARE THE BEST TECHNIQUES FOR EVALUATING DESIGNS EARLY ENOUGH TO ENABLE REDESIGN IF NECESSARY. GOOD PARAMETRICS MUST BE SUFFICIENTLY FLEXIBLE TO COPE WITH CHANGING TECHNOLOGY, HOWEVER, SO THAT ENGINEERS AND MANAGEMENT WILL HAVE CONFIDENCE IN THEIR RESULTS AND ACT ON THEM.

E-3A (AWACS) SUBSYSTEM DDT&E RESULTS

Since most major development programs are so long and change so fast, results of parametric model predictions are hard to come by. Aeronautical Systems Division is getting some good feedback on F-15 avionics predictions using the PRICE model -- less than 10 percent errors. We used PRICE on the AWACS subsystems at Electronics Systems Division with these results. PRICE gives a low, expected and high value, and you can see that for the radar and display, the range brackets the projected actual. We haven't figured out for sure what happened on the identification subsystem, but we suspect Boeing is showing only their subcontracted effort in the CIR and buried their integration, system/project management and test elsewhere in the WBS. In any event, I would prefer an outcome less than predicted if I had to be in error, for that indeed is a happy problem. In my opinion, PRICE is the state of the art in electromechanical system cost estimating. It is now being used by most major aerospace and electronics firms. The model still requires good inputs -- the basic need of any model. One of its greatest values has been to greatly increase the capability and productivity of our cost analysts. This, coupled with an estimating discipline and consistency has moved cost analysis closer to a science than an art. This closes our discussion of parametrics. We won't spend as much time on the other techniques because you are probably more familiar with them.

E-3A (AWACS) SUBSYSTEM DDT&E RESULTS

SUBSYSTEM	PRICE	COST AT COMPLETION (SEP 1975 CIR)
RADAR	84.3/99.3/120.8	111
DISPLAY	31.4/36.6/43.6	37
IDENTIFICATION	16.3	8

1. PRICE RUNS WERE MADE IN SEP 74 WHEN THE SUBSYSTEMS WERE LESS THAN 50% COMPLETE.
2. COSTS AT COMPLETION ARE FROM BOEING FORMS 1558-1 PLUS FEE. THE SUBSYSTEMS ARE APPROXIMATELY 95% COMPLETE.
3. WE QUESTION WHETHER ALL OF BOEING'S IDENTIFICATION EFFORT IS IN THE 8 MILLION. I&A, SYSTEM/PROJECT MGMT AND TEST MAY BE ELSEWHERE.

ANALOGY TECHNIQUE

The second principal technique is the analogy. We employ analogies in recalling our experience to judge what a new thing should reasonably cost. For that reason, analogies are used most often as reasonableness checks. They can't be used as the estimate itself because the new thing we are buying is never identical to something bought in the past.

ANALOGY TECHNIQUE

PHILOSOPHY: THE ANALOGY IS USUALLY USED AS A REASONABLENESS CHECK FOR TOTAL PROGRAM COST. SOMETIMES IT IS THE SYSTEM BEING REPLACED, E.G., F-4 IS THE ANALOGY FOR F-15, SACCS FOR SATIN IV. OTHERWISE, IT CAN BE ANY SIMILAR EXISTING SYSTEM.

EXAMPLES:

1. COBRA DANE AS A BASELINE FOR PAVE PAWS.
2. AWACS TESTING PROGRAM AS A BASELINE FOR AABNCP TESTING.
3. TV GUIDANCE AS A BASELINE FOR INFRARED MAVERICK GUIDANCE.
4. MAVERICK LASER SEEKER AS A BASELINE FOR THE CANNON LAUNCHED GUIDED PROJECTILE.

ENGINEERING (BUILD-UP) METHODOLOGY

The third technique is the build-up, which takes two forms. One can project costs from the recurring costs of development prototypes or if the system uses off-the-shelf components, a catalog can be used. Beware, however, that the sum of a system cost is greater than the sum of the subsystem costs.

ENGINEERING (BUILD-UP) METHODOLOGY

PHILOSOPHY: THIS METHOD IS USED MOST APPROPRIATELY WHEN A VERY FIRM TECHNICAL DEFINITION EXISTS OF WHAT IS TO BE PRODUCED. MOST COMMONLY, A BUILD-UP ESTIMATE IS AN EXTRAPOLATION FROM THE RECURRING COSTS OF BUILDING DEVELOPMENT PROTOTYPES OR PRE-PRODUCTION UNITS.

USING A CATALOG TO OBTAIN COMPONENT COSTS IS ALSO AN ENGINEERING APPROACH. IT CAN BE SOMEWHAT RISKY, HOWEVER, IF THE INTEGRATION PROCESS IS NOT TREATED ADEQUATELY.

EXAMPLES:
1. E-3A ICA - BUILD-UP
2. SEEK SET - CATALOG

BUILD-UP ESTIMATES

The build-up estimate for production is generally the most accurate technique in the inventory if the development program has reached an orderly conclusion. A glance at the steps shown makes it look like duck soup, but closer scrutiny can reveal some uncertainties in these inputs also. Labor rates are subject to union negotiations and bargaining. Some companies do not break out recurring from nonrecurring cost. Some management control systems poorly correlate dollars spent to work accomplished. Anyone who has watched material and purchased part availability and cost in recent years realizes how risky it is to place a deterministic value on them. One of our analysts blew the AF CAIG's mind when, by employing several sets of equally reasonable assumptions and this technique, she derived an estimate uncertainty range that was as wide as the value of the point estimate. As a footnote to this technique, comptroller cost analysts do not do classical industrial engineering type estimating. Program office analysts may employ some labor, material and overhead type considerations, but these are usually funneled to them by the contractor.

BUILD-UP ESTIMATES

1. MUST BE AT THE PRE-PRODUCTION STAGE OR LATER.
2. MAKE ITEM
   - A. BREAKOUT NON-RECURRING FROM RECURRING.
   - B. RELATE DOLLARS SPENT TO WORK DONE.
   - C. LABOR RATES OVER PRODUCTION PERIOD.
   - D. COST OF PURCHASED PARTS.
   - E. OVERHEAD RATES.
3. BUY ITEM
   - A. SOURCE SELECTION PROCESS.
   - B. LOOK AT SUBASSEMBLIES BUT NOT PARTS.
   - C. ASSESS RATIONALE AND OPTIONS.
4. EXPLORE EFFECT OF QUANTITY CHANGES ON OPTION PRICES.

HISTORICAL DATA

Another way to use historical data besides creating CER's is to calculate estimating factors for certain items in the Work Breakdown Structure. The Prime Mission Product is defined as all labor and material costs allocable to the prime mission equipment plus integration and assembly. Studies have shown that expenditures for system/project management, data, training, peculiar support equipment and initial spares are highly correlated with the prime mission product. There is some variability depending on whether the program is in development or production, how much software is present and whether the contractor is a prime or subcontractor. The factors are usually derived in one of two ways: either adopt the factors that actually occurred in the most closely related completed program or average the factors from a family of relevant programs. Some care must be taken to approximate the actual requirements of the new program. For example, it would be a mistake to use a factor for data derived from a program not requiring reprocurement data on a program which will require reprocurement data.

HISTORICAL DATA

PHILOSOPHY: DATA FROM PAST PROGRAMS ARE ALWAYS HELPFUL IN DERIVING REASONABLE ESTIMATES FOR WORK BREAKDOWN STRUCTURE ITEMS THAT LACK RIGOROUS DEFINITION. THEIR USE IMPLIES THAT THE PROGRAM BEING ANALYZED WILL FOLLOW THE SAME PROPORTIONAL WBS EXPENDITURES AS SIMILAR PAST PROGRAMS.

EXAMPLES: FACTORS OF PRIME MISSION PRODUCT IN THE AABNCP ICA FOR

1. SYSTEM/PROGRAM MANAGEMENT
2. DATA
3. TRAINING
4. AGE
5. SPARES

E-4 ICA METHODOLOGY

Each cost analysis will probably employ a variety of these four techniques based on the available relevant data. Here is an example of methodology used as an ICA for the E-4 Advanced Airborne Command Post derived early in the full scale development program. The aircraft modifications were based on a projection from an existing E-4A analogy, a simplified version of the more advanced E-4B being developed. The 1200 Kilovolt-Ampere estimate used the output of a validation-phase contractor generated engineering estimate. It was checked for reasonableness by comparing with the E-3A (AWACS) and B-1 power management development costs. This was the only subsystem that had a validation phase, and it is the only portion of the program that stayed on schedule and within original contractual cost. One of the biggest challenges was to define the 50,000 pounds of electronics so that the PRICE model could be run on the command, control and communications equipment and their integration. Surprisingly, this was accomplished in two weeks based on some expert contractor data and government engineering inputs. Fortunately, aircraft designers are very careful to keep close track of equipment weight, as it affects the aircraft center of gravity. Boeing's estimate for system test was deemed reasonable since it jibed very nicely with several other Boeing programs. The remainder of the WBS was rather ill defined, so we used factors from the E-3A program. This program had much in common with the E-4 program -- same contractor, modification of an existing aircraft, to be stuffed with tons of electronics. The ICA was accepted and actually became the OSD position on program cost.

E-4 ICA METHODOLOGY

WBS ELEMENT	DEVELOPMENT	PRODUCTION	SOURCE
AIRCRAFT MODS	E-4A DATA	E-4A DATA	E-SYSTEMS CONTRACT
INTERCHANGEABILITY	ENGR ESTIMATE	ENGR ESTIMATE	E-SYSTEMS
1200 KVA	ENGR ESTIMATE	ENGR ESTIMATE	BOEING
MISSION EQUIPMENT	PRICE	PRICE	EQUIPMENT DESIGNS
MISSION I & A	.46 (CFE & GFE)	.28 (CFE & GFE)	PRICE MODEL
AIRCRAFT I & A	.45 MISSION I & A	.45 MISSION I & A	BOEING E-4B DATA
SYSTEM TEST	ENGR ESTIMATE	ENGR ESTIMATE	BOEING
SYSTEM/PROJECT MGT	.23 PMP	.17 PMP	AWACS EXPERIENCE
DATA	.02 PMP	.03 PMP	AWACS EXPERIENCE
AGE	.06 NON-RECURRING PMP	.10 PMP	AWACS EXPERIENCE
TRAINING	.02 PMP	.03 PMP	AWACS EXPERIENCE

PRODUCTION QUANTITIES AND LEARNING CURVES

Another important technique in the analysts methodology bag is the learning curve. The concept of a learning curve has been employed as a mathematical model to explain improvements in actual unit costs over time. Much as you become speedier as you accomplish the repetitive functions of assembling a storage shed or erecting a stockade fence, so do the production line workers increase their efficiency to reduce touch labor and rework. Quantity discounts on material, although not strictly defined as learning, contribute to the effect and confirm the basic mathematical notion. Some companies do not wait for labor intensive products to experience learning. Instead they will automate production lines and use hard tooling for sufficiently large quantities. This front end investment results in reduced average unit costs, which again is approximated by greater learning.

There are three basic ways of predicting a learning curve. The best way is to get hard data from a production line producing a unit similar to that planned using the same manufacturing technology. The second way, which can be used either alone or as a check on the above, is to use a parametric relationship. Studies have shown that learning is a function of unit complexity, number produced, schedule duration and number of factory lines and shifts. The third way is to guess based on past rules of thumb like, "If you don't know, use a 90% unit curve for electronics." You can readily guess which of these three methods is least recommended.

Production program managers are excruciatingly aware of this, but it might be well to point out two major disruptions to learning: engineering change orders and production gaps.

One final caution: do not confuse learning curves with price improvement curves, which exhibit the effect of a company's pricing policy. If the cost of a second lot goes up, it is probably because the company took a bath on the first lot, not because their production people are dummies and didn't learn. The true learning curve is imbedded in the quote and reflects a higher first unit cost than the company negotiated in the first lot.

PRODUCTION QUANTITIES AND LEARNING CURVES

- THE AVERAGE UNIT PRODUCTION COST NORMALLY DECREASES AS THE NUMBER OF UNITS PRODUCED INCREASES DUE TO:
  - THE PRODUCER IS ABLE TO AUTOMATE PRODUCTION LINES THUS REDUCING TOUCH LABOR COSTS AND PRODUCTION TIME PER UNIT
  - THE SPREAD OF NON RECURRING COSTS OVER A LARGER NUMBER OF UNITS
  - LABOR EFFICIENCY INCREASES OVER LARGE PRODUCTION RUNS
  - QUANTITY BUYS OF RAW MATERIALS AND COMPONENTS REDUCES MATERIAL COSTS
  - DESIGN STABILIZATION AND ASSOCIATED ECP AND REWORK COSTS ARE SPREAD OVER LARGER PRODUCTION COSTS

- THE DECREASE OF UNIT PRODUCTION COST AS A FUNCTION OF LARGER PRODUCTION RUNS IS EXPRESSED BY "LEARNING CURVES"

LEARNING CURVE

The nature of a learning curve is a rapid reduction at first but with successively less reduction with each new unit. The unit cost ultimately flattens out at what can be viewed as an irreducible minimum. The mathematical model which best captures this process is the logarithmic or exponential model:

$$Y = AX^b$$

where Y is the unit cost of the Xth unit, X corresponds to the numbered unit and b is a slope parameter, almost always a negative fraction. The beautiful feature of this equation is that it is a straight line on log-log paper.

Recall that this is equivalent to the form of the radar cost estimating relationship:

$$\ln Y = \ln A + b \ln X$$

Now, the rationale becomes the following: the percent reduction in unit cost is proportioned to the percent <u>increase</u> in the number of units and depends on how many you have already produced.

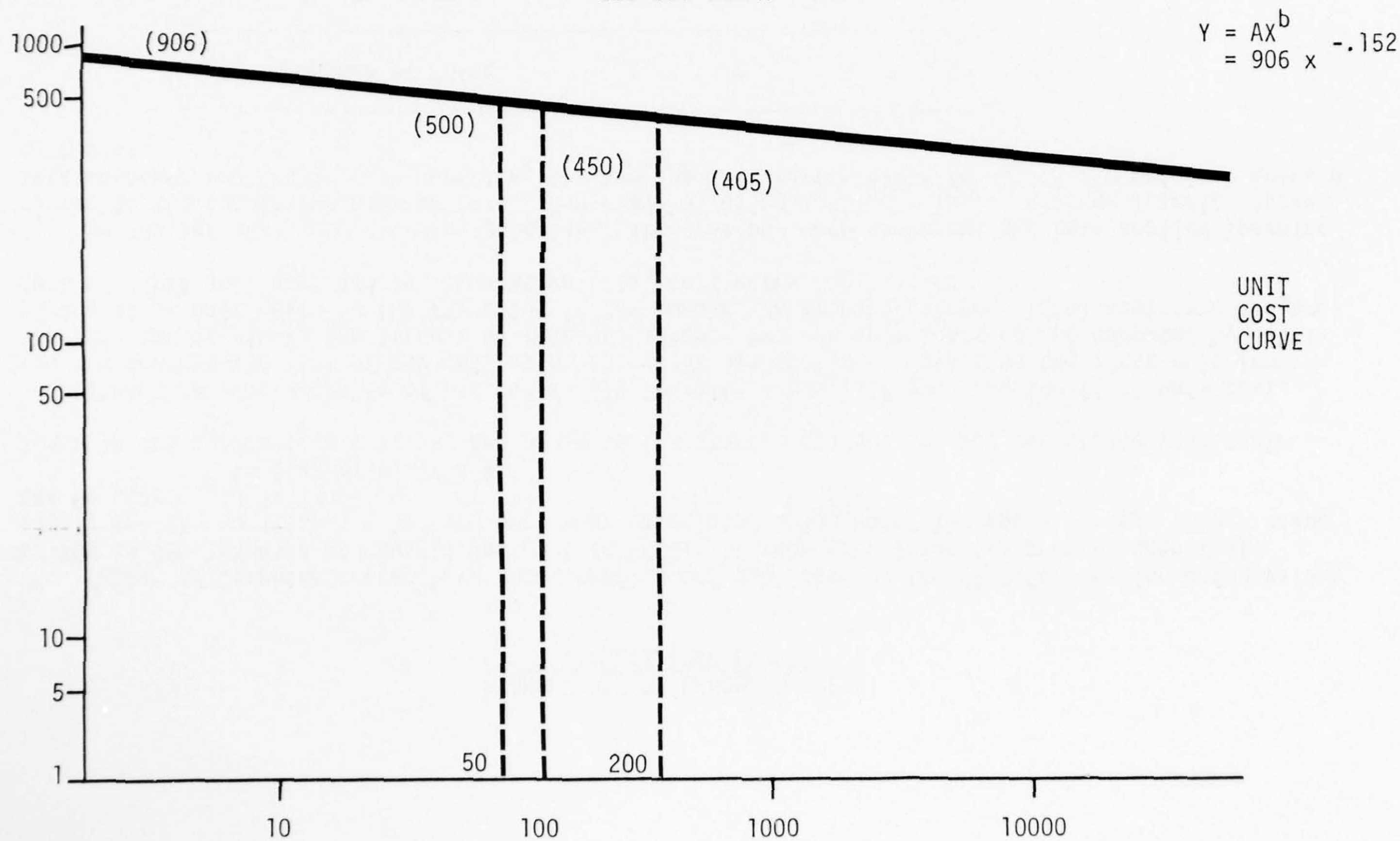
Suppose, for instance, that we are working with a 90% unit learning curve. The learning curve says that every time you double the quantity, the unit cost comes down 10%, e.g., the second unit is 90% of the first, the fourth unit is 90% of the second, etc. This viewgraph shows the effect of 90% unit learning when the first unit costs \$906. Note that while the 50th unit costs \$500, when we double the quantity to 100, the 100th unit costs 90% of 500 or \$450; the 200th unit costs 90% of \$450 or \$405, etc.

LEARNING CURVE

THE UNIT PRODUCTION COST NORMALLY DECREASES

AS THE QUANTITY OF UNITS INCREASES

LOG LOG GRAPH



EXAMPLE USE OF LEARNING CURVE
(TABLES (85% SLOPE)

Tables of learning curves have been compiled and published by the RAND Corporation using values of 70% to 99% learning and quantities of 1 to 2000. If your quantities are greater than that, simply use the equation $Y = AX^b$ and grab your calculator which hopefully has a Y^X key. The b value can be stored and is equal to:

$$\ln(\text{learning } \%)/\ln 2.$$

Punch in the appropriate unit, X, and raise to the stored exponent and you can create your table.

These are some examples of uses of an 85% learning curve. If you know the first unit cost, you can compute the cost of any unit using the right hand column. Computing the first unit from the Xth unit is simply the inverse of this operation. Average unit costs can be computed by multiplying first unit costs by the Xth entry in the cumulative average column. Total costs are the product of first unit cost and the cumulative total cost entry for X units.

Be advised that some cost analysts have taken yet one more short cut and have applied learning curves to the cumulative average cost. For example, using a 93% <u>cumulative average</u> learning curve says whenever you double your quantity, the <u>average</u> unit cost shrinks to 93% of the original average unit cost.

Number of Units	1	2	3	4
Average Unit Cost	1	.93	.89134	.8649

This usage represents a shortcut that is not as defensible analytically, but it can be a timesaver. Since average unit costs are usually what we are trying to compute, this procedure enables them to be read right out of the table based on a first unit cost of 1.

EXAMPLE USE OF LEARNING CURVE
(TABLES (85% SLOPE)

UNIT NO.	CUM TOTAL	CUM AVE	UNIT
1	1.00000	1.00000	1.00000
.	.	.	.
50	25.51311	0.51026	0.39962
.	.	.	.
100	43.75387	0.43754	0.33968
.	.	.	.
150	59.88829	0.39925	0.30887
.	.	.	.
200	74.78851	0.37394	0.28873
.	.	.	.
250	88.83272	0.35533	0.27401
.	.	.	.
300	102.23008	0.34077	0.26254
.	.	.	.

GIVEN: 1ST UNIT COST = $100,000

TOTAL PRODUCTION COST
(300 UNITS) = (102.23008) (100,000)
= $10,223,008

AVERAGE UNIT PRODUCTION COST
(300 UNITS) = (0.34077) (100,000)
= $34,077

COST OF 300TH UNIT = (0.26254) (100,000)
= $26,254

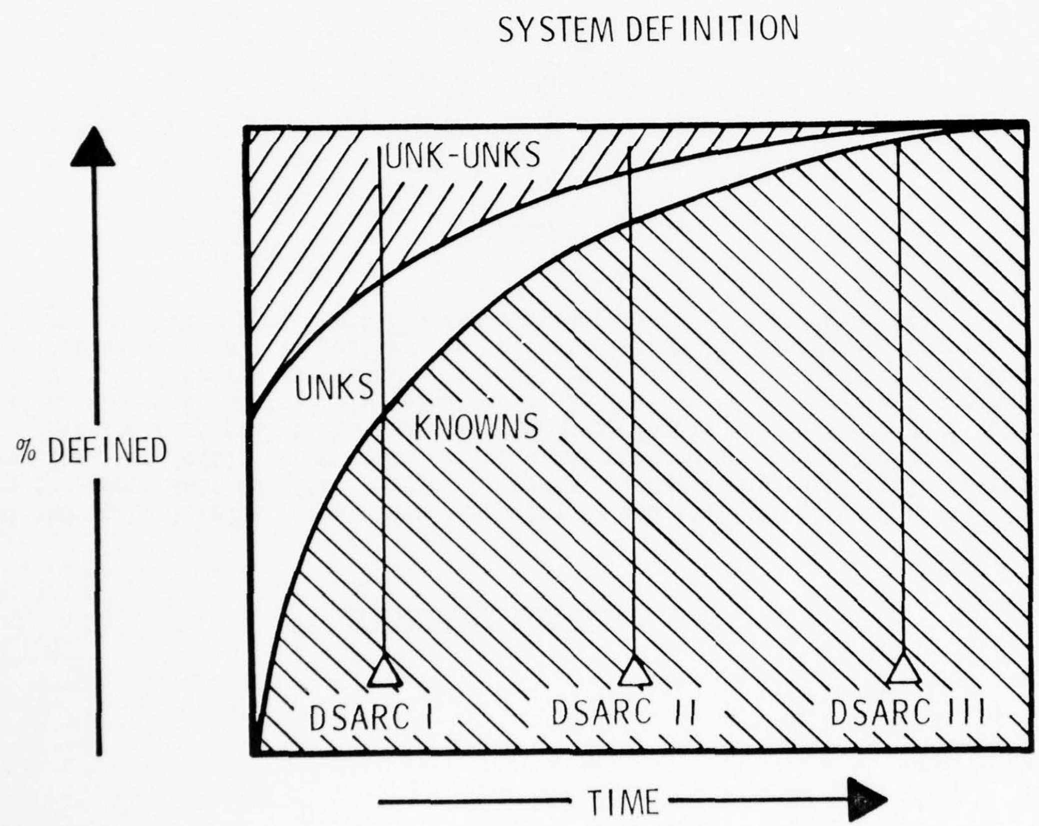
GIVEN: 200 UNITS PRODUCED
COST OF 200TH UNIT = $10,000
1ST UNIT COST = $\frac{10,000}{0.28873}$
= $34,634

COST OF PRODUCING 100 MORE
UNITS = (102.23008-74.78851) (34,634)
= $950,411
AVERAGE UNIT PRODUCTION COST
FOR NEXT 100 UNITS = $\frac{950411}{100}$ = $9,504
COST OF 300TH UNIT = (0.26254) (34634)
= $9092

COST RISKS

Only the statistical decision theorists draw a sharp distinction between risk and uncertainty. Risk says you are in the probabilistic arena but know the distribution whereas uncertainty says probabilistic and unknown distribution. This corresponds roughly to the known unknowns (risk) and the famous "unk-unks" - unknown unknowns (uncertainty).

COST RISKS


SYSTEM DEFINITION
% DEFINED
UNK-UNKS
UNKS
KNOWNS
DSARC I
DSARC II
DSARC III
TIME

COST UNCERTAINTY VERSUS COST RISK

Technical and schedule risk, model input uncertainty and statistical variability in estimating techniques are the components of risk. For risk averse program managers, I would suggest a budgeting strategy that explicitly incorporates a technical program and schedule which allows for difficulties. Have the cost analyst be ample in his model inputs and have him give you a one standard deviation above the most likely value for an estimate. We have already shown that requirements uncertainty is what drives overruns. The best way to identify it is to try to define and quantify it as soon as you can. If you have to sell a thing called management reserve, perhaps requirements uncertainty is the best vehicle after risk has already been pumped in.

COST UNCERTAINTY VERSUS COST RISK

- SOME COST UNCERTAINTY IS INEVITABLE
  - SENSITIVITY ANALYSIS
    - REQUIREMENTS VARIATION
    - COST ESTIMATING VARIATION

COST RISK IS DIRECTLY ASSOCIATED WITH AREAS OF TECHNICAL AND SCHEDULE RISK

- MAY BE QUANTIFIED AS A MEASURE OF CONFIDENCE IN THE COST ESTIMATES
- MAY BE RELATED TO TECHNICAL/SCHEDULE RISK

TROUBLESOME PROBLEMS FOR COST ANALYSIS

Cost analysis still has several significant problems to solve on its way to assisting the program manager and the acquisition process. Over the past several years, many operations research techniques have been adopted by cost analysts who have been looking at potential applications in financial analysis. They are almost always stopped by a lack of credible data. The Cost/Schedule Control System Criteria have been of some help here, but the problem persists. The computer software development process is still understood only by a few, and Dr. Currie himself has admitted to the Congress how poorly we manage it. Currently we have no reliable, consistent software technical and cost data base. Software has been elevated to level 2 of the WBS in several new contracts, which promises to provide some cost visibility in the next few years. Probably the biggest hangup for cost is the ubiquitous lack of definition concurrent with a pressing requirement for budgetary data. Every cost analyst I know earnestly desires to know how well he predicted. Changing program baselines, however, rarely afford him or his supervisor that opportunity. While telling the whole cost truth has never been a problem for the Comptroller organization, it has been a problem for many a program manager. The fear of cancellation still causes most managers to understate the fiscal requirements or at least to parcel them out in pieces which individually may be more acceptable to the Headquarters and Congress. The additional emphasis on operating and support cost brings to mind that we currently have no CER's to directly relate design variables to O&S costs. This is a real stumbling block to making good life cycle cost decisions early in development when they will effect the greatest benefits. Finally, a problem especially for Electronic Systems Division and Space & Missile Systems Organization is that unique, low volume production programs defy one to locate an analogy, and they sometimes require performance outside the useful range of some CER's. They do, of course, obviate the usual high volume production program arguments over what learning curve to use.

TROUBLESOME PROBLEMS FOR COST ANALYSIS

1. TECHNIQUE RICH - DATA POOR.
2. SOFTWARE IS WILD - WE DON'T KNOW WHAT WE BOUGHT AND WHAT RESOURCES WERE REQUIRED.
3. LACK OF SPECIFIC PROGRAM DEFINITION. ESTIMATES ARE REQUIRED BEFORE WE KNOW WHAT WE ARE BUYING.
4. CHANGING PROGRAM BASELINES - MAKES DETERMINATION OF PREDICTION ACCURACY DIFFICULT.
5. POLITICAL UNACCEPTABILITY OF ADVERSE RESULTS.
6. INABILITY TO RELATE DESIGN VARIABLES TO OPERATING AND SUPPORT COST DRIVERS.
7. UNIQUE LOW-VOLUME PRODUCTION PROGRAMS.

AD-A042 935 DEFENSE SYSTEMS MANAGEMENT COLL FORT BELVOIR VA F/G 14/1
USING COST ANALYSIS TO BREAK THE OVERRUN HABIT.(U)
MAY 77 R W GRIMM

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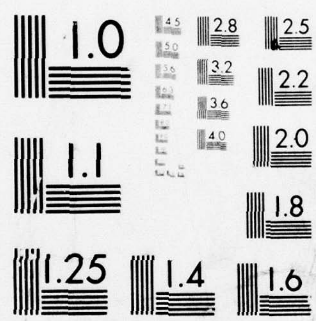

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

ONGOING COST RESEARCH TO AID IN FUTURE ESTIMATING

What is cost analysis doing to solve some of these problems? Escalation (inflation) has not previously been discussed here, but in 1973 and 1974 it caused a violent "hiccup" in the way we did business. A great deal of work is taking place to predict weapon system escalation. The basic problem is to be able to identify it far enough ahead to impact the budgeting process. We are working more closely with program offices to insure that we know what we bought and for how much. We just cannot abide the negligent purging of our most current corporate memory. We are taking a new tack on costing software by simulating the development process, capturing the testing and rework process to gauge their effect on cost. We are routinizing more of the clerical tasks through using the computer. This frees the analyst to spend more effort on definition and other difficult tasks and enables him to be more productive. We are using analysis of variance techniques to provide a formal, rigorous derivation of the factors we use so often.

ONGOING COST RESEARCH TO AID IN FUTURE ESTIMATING

1. ESCALATION STUDY
2. DATA BANK, CORPORATE MEMORY FILE
3. SOFTWARE COSTING - DEVELOPMENT SIMULATION
4. AUTOMATION OF ROUTINE TASKS - COST AND BUDGET APPLICATIONS LIBRARY (CABAL)
5. COST FACTOR STUDY FOR DIFFICULT PORTIONS OF WORK BREAKDOWN STRUCTURES (AGE, DATA, TRAINING, MANAGEMENT, TEST, SPARES)

SUMMARY

In conclusion, the necessary condition for good cost analysis is an intimate understanding of the program. Detailed program definition will enable the derivation of a range of expected costs which can greatly aid in contingency planning. If the ranges are too large, the signal is there to ask more questions and generate more specific definition. The best way to break the cost overrun habit is teamwork and communications among knowledgeable, dedicated program office and functional specialists. The habit can and must be broken. Who of you will be the first?

SUMMARY

BEST COST ESTIMATE WILL BE DERIVED BY THE COST ANALYST HAVING AN INTIMATE UNDERSTANDING OF THE PROGRAM.

- BROAD PROGRAM DEFINITION WILL PERMIT USE OF DIFFERING METHODOLOGIES.

CLOSE RELATIONSHIP WITH PROGRAM OFFICE ENGINEERS AND PROGRAM CONTROL PERSONNEL ESSENTIAL.

- FACE-TO-FACE DIALOGUE.

PO DIRECTOR MUST UNDERSTAND ALL FACETS OF THE COST ESTIMATE.

- WILL PERMIT HIM TO JUDGE ITS ACCURACY AND RISK.
- WILL ALLOW HIM TO ASSESS ITS CURRENCY.